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PATENT SPECIFICATION

(11) 1 549 421

(21) Application No. 14400/76 (22) Filed 8 April 1976
(31) Convention Application No. 566969
(32) Filed 10 April 1975 in
(33) United States of America (US)
(44) Complete Specification published 1 Aug. 1979
(51) INT CL² B32B 3/26 5/18
(52) Index at acceptance
B5N 0326 0518

(19)

(54) EMBOSSED, DEFORMABLE LAMINATE

(71) We, SCOTT PAPER COMPANY, a Corporation organized and existing under the laws of the State of Pennsylvania, United States of America, of Industrial Highway at Tinicum Island Road, Delaware County, State of Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention concerns embossed laminated sheet structures and particularly flexible open-cell foam with deformable sheet laminated and embossed into the foam surface.

Articles have been manufactured in which a deformable sheet such as a plastics film has been laminated to flexible foam with the surface embossed. Typically, these products are designed as wall panels, floor coverings or rug underlay cushions in which the film material is added for durability and abrasion resistance and the embossing pattern is normally designed for aesthetic reasons or to impart rigid regions (see U.S. Patents 2,669,527; 2,978,006 and 2,572,470. Examples of foam-to-sheet laminates are contained in U.S. Patents 3,454,413 issued July 8, 1969 to Philip Miller and 3,425,882, issued February 4, 1969 to Albert L. McConnell et al. Prior art relating to embossed, perforated laminates is disclosed in U.S. Patent 3,292,619 while embossed foam rubber-to-fabric laminates are disclosed in U.S. Patent 2,752,279.

According to the present invention, there is provided a laminate capable of conforming to a specific three-dimensional configuration having concave characteristics by the laminate deforming according to a pre-selected regular pattern, said laminate comprising:

(a) a flexible, open-cell foam having a thickness of at least 1/8 inch and a deformable sheet adhesively laminated to a surface of the open-cell foam, said sheet having sufficient thickness and strength to result in the laminated surface being less flexible than an unlaminated surface of the foam;

(b) a pre-selected regular pattern comprising land, valley and sidewall areas defined by at least three intersecting sets of parallel fold lines impressed into the laminated surface;

(c) each fold line resulting in land areas being spaced apart on either side of the fold line, which land areas contact upon concave bending of the laminated surface along the fold lines;

(d) each fold line readily accommodating bending of the laminated surface by deforming up to a maximum concave bend angle, A, at which angle contact of adjacent land areas interferes with additional concave bending;

(e) an average distance between two parallel fold lines within a set, d, and the maximum concave bend angle, A, at which a land area touches an adjacent land area being defined by the formulas $A \gtreqless 180\ l/\pi r$ and $d \lesseqgtr r/2$ sine 1/2A, wherein l and r are geometric characteristics of a pre-selected concave arc of the specific three-dimensional configuration to which the laminate will conform with the deformation essentially limited to the pre-selected pattern, said pre-selected arc having an arc length l, and an arc radius r;

(f) the minimum angle of intersection between any two sets of parallel fold lines being 25°,

(g) the sum of the angles of intersection between one set of parallel fold lines and each other set of parallel fold lines being at least 75°.

Also in accordance with the present invention there is provided an improved passenger carrying vehicle of the type comprising motive means and a passenger compartment having a cover with concave curves particularly in the areas where the cover joins with side walls of the passenger compartment, wherein the improvement comprises the inclusion of a laminate in accordance with the invention as a headliner for the passenger compartment attached to and conforming with the inside surface of the passenger compartment cover, with the unlaminated surface of the foam being attached to the passenger compartment cover and the laminate sheet surface being the surface exposed to the inside area of the passenger compartment.

Further in accordance with the present invention there is provided a method of manufacturing a laminate capable of conforming to a three-dimensional configuration having concave and convex characteristics by the laminate deforming according to a pre-selected regular pattern, said method comprising:

(a) adhesively laminating a deformable sheet to a sheet of flexible open-cell foam having a thickness of at least 1/8 inch;

(b) impressing into the laminated surface a pre-selected regular pattern comprising land, valley and side wall areas defined by at least three intersecting sets of parallel fold lines;

(c) each fold line resulting in spaced-apart raised land areas on either side of the fold line which land areas contact upon concave bending of the laminated surface along the fold lines;

(d) each fold line readily accommodating bending of the laminated surface by deforming up to a maximum concave bend angle, at which angle contact of adjacent land areas interferes with additional concave bending;

(e) the average distance between two parallel fold lines within a set being equal to or less than the value obtained from the equation $d=r/2 \text{ sine } 1/2A°$ wherein A° is the degrees of the maximum concave bend angle having a magnitude equal to or greater than $180\, l/\pi r$ in which l and r are geometric characteristics of a pre-selected concave arc of the three-dimensional configuration to which it is desired that the laminate conform with deformations essentially limited to the pre-selected regular pattern, with l representing the arc length, and r representing the arc radius;

(f) the minimum angle of intersection between any two sets of parallel fold lines being 25° and;

(g) the sum of the angles of intersection between one set of parallel fold lines and each other set of parallel fold lines being at least 75°.

The expressions "embossed into the laminated surface" and "impressed into the laminated surface" herein are intended to refer to a deformation of the exposed surface of the deformable sheet laminated to the foam, with a corresponding deformation of the underlying foam.

By the expression "concave bending" herein, is meant such bending of the laminate that the patterned surface assumes concave forms.

The term "fold line" herein refers to a line of weakness impressed into the laminated surface, at which the laminate will fold or crease upon being subjected to bending stresses.

In the present invention, a flexible laminate is provided that is capable of conforming to a three dimensional configuration having concave and convex characteristics with the laminate deforming according to a pre-selected regular pattern. The laminate comprises a flexible, open-cell foam sheet having a thickness of at least 1/8 inch and a deformable sheet adhesively laminated to a surface of the foam. The pre-selected regular pattern is embosed into the laminated surface and is composed of a regular pattern of land, valley and sidewall areas defined by at least three intersecting sets of parallel fold lines impressed into the laminated surface. Each fold line is recessed into the laminated surface and thereby has sufficient depth and width to produce spaced apart raised land areas in the embossed laminated surface. Concave bending of the laminate results in flexing of the foam and bending of the embossed surface along the fold lines (rather than deforming the raised land areas) up to a bend angle at which angle contact of adjacent land areas interferes with additional concave bending. Since the fold lines are in a pre-selected regular pattern, the deforming of the laminated surface occurs in the regular pattern. The pre-selected regular pattern embossed into the laminated surface must conform to precise geometric characteristics which are related to the characteristics of the three dimensional configuration to which the laminate will conform. Preferably, the foam is a flexible open-cell polyurethane foam having a layer of polyurethane film adhesively attached to the foam and with perforations through the film to permit sound to pass through the film and be absorbed in the open-cell network of the foam. Such a preferred laminate is particularly useful as a headliner in a motor vehicle passenger compartment because of its acoustical properties and its ability to contour to the irregular surfaces of the roof of the vehicle.

In the accompanying drawings,

Fig. 1 is a top view of the laminate,

Fig. 2 is a perspective view of the laminate,

Fig. 3 is a section through the laminate along the line 3—3 of Fig. 1,

Fig. 4 depicts the product of Fig. 1 bent in a concave arc, and

Fig. 5 depicts a process for producing the laminate.

Any flexible, open-cell foam material may be employed in practicing this invention. Flexible, open-cell foams are foams having cell walls which have been broken which includes foams whose cell walls have been partially or totally removed. Reticulated foams are flexible foams with their cell walls removed. Both organic and inorganic flexible foams are suitable for practicing the present invention. Typical organic materials from which flexible open-cell foams can be produced includes polyurethane, polystyrene, polyethylene, vinyl resin (e.g., plasticized polyvinylchloride), cellulose acetate, natural rubber and synthetic rubber latexes. Typical inorganic materials from which flexible foams have been produced include metals and glasses. Suitable

flexible foams made from inorganic or organic materials are disclosed in U.S. Patent 3,175,025, entitled "Process for Bonding and/or Reticulation", issued to H. Geen et al on March 23, 1973.

Foams that can be adhesively activated upon exposure to heat are preferred, which include both foamed thermoplastic resins and foamed elastomers. Examples of such suitable open-cell foams are polyether or polyester based polyurethane foams and foams from vinyl polymers such as polyvinyl chloride and vinylchloride copolymers. Many different types of flexible open-cell foams are known especially for their acoustical properties and, accordingly, the selection of any particular one is not critical to the practice of this invention and well within the abilities of those possessing ordinary skill in the foam art.

The most preferred cellular material for practicing the present invention is flexible open-cell polyurethane foam.

The thickness, density, cell pore size and degree of cell openness of the foam are capable of wide variations with the selection of specific values for these parameters being dictated by the desired end use of the product. Particularly preferred are acoustically controlled foams such as flexible open-cell polyurethane foams especially those having a cell size to provide from 40 to 90 pores per inch and a density of from 1 to 15 lbs. per cubic foot.

The deformable sheet material can be any woven or nonwoven substantially water-impenetrable sheet such as a plastics film or a metal foil such as aluminum foil. The selection of a specific sheet material in combination with the thickness of the sheet material must be such so that the sheet is capable of being shaped into the pre-selected regular pattern impressed into the sheet and foam material. Organic materials which are capable of being so shaped are usually called elastomeric while suitable metallic materials are referred to as being malleable.

Suitable sheet material includes any of the well-known thermoplastic and thermosettable film-forming materials that can be mechanically and/or thermally deformed into a preselected pattern of land, valley and side wall areas and which preferably, softens sufficiently during an embossing step at elevated temperature to adhesively bond to the foam. Examples of suitable, thermoplastic film materials are natural substances such as crude rubber and synthetic materials such as polyvinyl chloride, nylons, fluorocarbons, linear polyethylene, polyurethane, polystyrene, polypropylene, cellulose acetate, cellulose nitrate and acrylic resin.

Thermosettable materials are capable of undergoing some softening under mild heating prior to their thermosetting or rigidification (usually caused by cross-linking) and are therefore suitable. When thermosettable materials are employed, precautions should be taken to prevent the thermosettable material from setting prior to being laminated to the foam and deformed into the preselected regular pattern (this can be easily controlled by adjusting embossing temperature and time). Examples of suitable thermoset film materials are polyesters, amino resins and silicone polymers.

Metal foils are also sufficiently deformable to be suitable for use as the sheet material especially the metals which soften more readily when exposed to heat, such as aluminum, aluminum alloys, tin, tin alloys, copper, and copper alloys.

Preferred deformable sheet materials are polyesters, polyethylene, polyvinylchloride, polypropylene, polyurethane, and similar elastomeric materials. Particularly preferred is polyurethane film. Many of the sheet materials can be formed into threads and woven into a tight-weave fabric to form a substantially water-impenetrable sheet suitable for use in making the laminate.

The deformable sheet material can vary in thickness with the selection of any particular thickness depending upon considerations such as the desired degree of durability and cleanability of the laminate surface, the plasticity of the material selected at elevated temperatures and the malleability of the materials selected. Preferred sheet thickness is from 0.5 mils to about 20 mils.

Regardless of the material from which the foam is produced, all flexible foams possess a common characteristic; namely, that a sheet of foam material can be bent into a three dimensional configuration including convex and concave curves without any apparent wrinkling or creasing of the surface of the foam material. Necessary deforming of the surface of the foam sheet apparently occurs within individual cells of the flexible foam, rather than creasing or folding of the surface.

When a deformable sheet material is adhesively laminated to a sheet of flexible open-cell foam, the laminated surface bends and wrinkles when the sheet of foam material is bent into three dimensional concave configurations that would not bend or wrinkle an unlaminated surface of the foam. This wrinkling phenomenon upon concave bending is believed to be related to the dimensional change in the surface of the foam sheet material when it is deformed into a three dimensional concave configuration. Previous to lamination, the deformations in the foam surface would have been accommodated by compressing of the cells which changes the size of the flexible cells that make up the surface of the foam sheet. After a deformable sheet is adhesively attached to a surface of the foam, this deforming and flexing of the cells at the laminated surface is inhibited

and the surface tends to bend, fold and wrinkle in order to accommodate the dimensional changes caused by the compressive stress that accompanies concave bending of the laminated surface.

The thickness or strength characteristics of a deforamble sheet that will inhibit flexing of the laminated surface of the foam varies depending upon the flexibility characteristics of the foam. However, sheets having a thickness of at least about 0.5 mils generally have sufficient thickness and strength to impede the flexing and deforming of the foam surface.

The folding or wrinkling of the laminated surface is less pronounced with very thin foam sheets. A very thin foam sheet will stretch to accommodate the less yielding characteristics of a deformable sheet material, thereby lessening the formation of wrinkles upon concave bending of the laminated surface. Accordingly, the utility of the present invention is most pronounced with foam thicknesses of at least 1/8 inch.

It has been discovered that irregular wrinkles or folds in the laminated surface can be eliminated when a preselected regular pattern comprising land, valley and side wall areas defined by at least three intersecting sets of parallel fold lines is impressed into the laminated surface.

Each fold line is recessed below the land areas by having sufficient depth and width to result in spaced apart raised land areas. Typically, the fold lines have a depth of from about 0.04 inches to about 0.25 inches and have sufficient width so that adjacent land areas separated by the fold line do not touch upon folding along the line at an angle of about 2°.

The average distance between parallel fold lines within each set is from 0.1 inches to about 1.5 inches and is measured from center to center of adjacent parallel fold lines. The average distance between lines within one set may be the same or different than the average distance between fold lines in another set of parallel fold lines.

The pre-selected regular pattern comprising land, valley and sidewall areas is defined by at least three intersecting sets of parallel fold lines impressed into the laminated surface. Preferred are four sets of intersecting parallel fold lines. The angle of intersection between parallel fold lines in one set and parallel fold lines in any other set is at least 25° and the sum of the angles of intersection between parallel fold lines in one set and parallel fold lines in each of the other sets should be at least 75°. Preferred are four sets of parallel fold lines with the first and second sets perpendicular to each other and with the third and fourth sets perpendicular with each other and intersecting the first and second set at an angle of about 45°. Such a configuration of four sets of parallel fold lines is shown in Fig. 1 in which each fold line has sufficient depth and width to result in spaced apart raised land areas on either side of the fold line. The land areas tend to touch upon concave bending of the laminated surface along the fold line. The concave bend angle at which land areas touch is referred to as the maximum concave bend angle which is shown in Fig. 3 as Angle A.

In Figure 1, the land areas 1 are triangularly shaped crowns and are produced by recessed V-shaped fold lines 2 impressed into the foam and the deformable sheet. The side view of the laminated product shown in Fig. 3 shows the V-shaped fold lines which are capable of accommodating a maximum concave bend angle A shown in Fig. 3. The opposing surfaces of the land areas (10 and 11 shown in Fig. 3) touch when the laminated surface is bent in a concave arc as shown in Fig. 4. The arc shown in Fig. 4 corresponds to the maximum concave curvature that can be accommodated with deformation essentially limited to the fold lines. Unexpectedly, with curves greater than the maximum concave curvature the deformations in the laminated surface still occur in the regular pattern defined by the fold lines although the pattern is altered to some extent. Accordingly, an aesthetically pleasing pattern is maintained.

Fig. 2 depicts a sheet of foam 3 having deformable sheet 4 laminated to the top surface employing the preferred pre-selected pattern shown in Fig. 1. The relative thicknesses of the foam sheet and the deformable sheet is shown in Figs. 2, 3 and 4.

The pre-selected pattern can vary considerably, it only being essential that the pattern be composed of at least three sets of intersecting fold lines and that the angle of intersections meet the minimum angles defined above.

The required average distance between each parallel fold line within a set, (d shown in Fig. 2) and the maximum concave bend angle, (A shown in Fig. 3) are related to the concave curvatures of the three dimensional configuration to which the laminate is desired to conform with the deformation in the laminated surface being essentially limited to the pre-selected pattern.

For each set of parallel fold lines, the relationship between the maximum concave bend angle, A°, and the average distance between two parallel fold lines within a set, d, has been discovered to be controlled by the following mathematical relationships:

$$d \leqq r/2 \text{ sine } 1/2A^\circ$$
$$A^\circ \geqq 180\ 1/\pi r$$

in which l and r are geometric characteristics of the maximum concave arc of the three dimensional configuration to which the lamin-

ate is desired to conform, said arc having an arc length, l, and arc radius, r, and arc degrees, C°.

The values for A° and d for the regular pattern are pre-selected in accordance with the above formulas with the values for the arc length, l, and the arc radius, r being the values for the maximum pre-selected concave arc of the three dimensional configuration to which the laminate is desired to conform. Therefore, the pre-selected values for l and r control the minimum value for A° and the maximum value for d for the pre-selected regular pattern according to the above mathematical relationships.

A headliner for a passenger compartment of a motor vehicle is an example of the utility of the laminate of the present invention having a pre-selected regular pattern that will accommodate the deformation encountered when the laminate is contoured to the inside surface of the vehicle's roof. For a motor vehicle headliner, usually the maximum concave curvature to which it is desired that the laminate conform corresponds to an arc having a curvature of 10° and arc length of 3 inches and an arc radius of about 17 inches. These values, when inserted into the formula results in a minimum value for A° of about 10° and a maximum value for d of about 2.8 inches. With these values for A and d, a pattern can be readily selected for the laminate which will be suitable for contouring to such a motor vehicle's roof. (The pattern must have an average distance between two parallel fold lines within a set of about 2.8 inches or less and the fold lines must be capable of accommodating a fold angle of at least about 10°). Since aesthetically pleasing designs are maintained at curvatures somewhat greater than the pre-selected value, it is possible to employ values for A that are about 10% less the value obtained from the formulas. Furthermore, the pre-selected arc of the three dimensional configuration need not be the arc having the greatest curvature because some deformations may be acceptable for the specific application.

When determining the characteristics of the concave arc to which the laminate will conform, arcs of various lengths and degrees but having the same arc radius are all segments of the same circle and, accordingly, are equivalent with respect to the dimensions of the pre-selected regular pattern required, but result in different values for A° and d from the above formulas. However, the values for A° and d for such arcs having the same arc radius are related by having the same ratios of A°/d for the pre-selected pattern and, accordingly, are considered equivalent for the purposes of the invention. Pre-selected regular patterns having the same A°/d ratio are therefore equivalent with respect to the functionality of this invention.

For applications of the laminate as a liner for motor vehicle roofs, it is preferred that the pre-selected regular pattern have the following values:

depth of the fold lines of from 0.04 to 0.50 inches,

space between adjacent land areas (width of the fold lines) be from 0.05 to 0.50 inches or a distance between parallel fold lines (width of the land area) of from 0.1 to 1.5 inches;

maximum concave bend angle of from 2° to 60°, with 2° to 30° particularly preferred,

foam thickness of at least 1/8 and more preferably from 3/16 inches to 2 inches, and

deformable sheet thickness of from 0.5 mils to 20 mils.

For a motor vehicle headliner, it is especially preferred to employ the pattern depicted in Fig. 1 for the pre-selected regular pattern with a distance between fold lines of about 1/4 inch and concave bend angle of about 15° and be pre-selected for concave arcs having an arc length, l, of from 1/8 inch to 5 inches and an arc radius, r, of from 1 inch to 10 inches.

Fig. 5 depicts a process for producing the laminate in which foam 3 is fed from a roll past a heat source 9 and through embossing rolls 7 and 8. The deformable sheet 6 is fed from roller 5 through the embossing rolls 7 and 8 while contacting the top surface of the foam 3. The desired pre-selected pattern to be embossed is reproduced on the upper embossing roll 7 in relief (the valleys of the embossed pattern corresponding to land areas on the embossing roller). A heat source 9 adhesively activates the top surface of the foam and/or the lower surface of the sheet. The heat source could be the embossing roller 7 itself. Thermo-deformable sheet may contour to the cellular structure of the foam during the embossing step when sufficient elevated temperature is employed for adhesively activating the foam or the sheet. This contouring of thermo-deformable sheet to the cellular structure produces a slight irregularity to the sheet surface, particularly on the sidewalls and valleys of the pre-selected regular pattern.

Manufacture of the laminate can be accomplished in many ways other than the preferred method discussed above and depicted in Fig. 5. For example, deformable sheet can be embossed into the foam in a pre-selected pattern by mechanically impressing the embossed pattern into the sheet material and the foam simultaneously at elevated temperatures. In this way, the sheet material is both mechanically and thermally deformed into the valley areas during embossing which, for practical and economic considerations, dictates a thin sheet thickness which facilitates the mechanical deforming of the sheet during embossing at the slight elevated embossing temperatures employed. This practical thickness varies depend-

ing upon the sheet material selected and would usually be in the area of a fraction of a mil (e.g., 1/10 mil) to about 20 mils thick with from about 4 to about 8 mils preferred. The use of a slightly elevated temperature during mechanically embossing the sheet and the foam simultaneously into the pre-selected pattern is preferred since the foam and sheet materials will usually deform into the desired pattern at elevated temperatures, which pattern will be retained in the embossed surface upon cooling of the laminate.

In addition to simultaneous thermo-mechanical embossing, other methods could be employed such as mechanically or thermally impressing the pre-selected pattern into the foam and then laminating by adhesively contacting the sheet to the pre-selected pattern already embossed into the foam. For example, the pre-selected pattern can be cut into a surface of the foam and then the sheet impressed into the pre-selected pattern surface of the foam along with an adhesive to secure the sheet to the foam.

EXAMPLE I

A 70 pore per inch flexible open cell polyurethane foam sheet about 1 inch thick was passed through embossing rolls as shown in Fig. 5 at a speed of about 20 feet minute. Simultaneously, a sheet of 4 mil thick Tuftane® film (a polyester based polyurethane film having a specific gravity of 1.21 and containing anti-oxidant and ultraviolet stabilizers sold by B. F. Goodrich Chemical Company as TF-312) was fed through the embossing rolls while contacting the top surface of the foam. The embossing roll was heated to a temperature of about 500°F. and had a pre-selected pattern in relief so as to emboss the pattern shown in Fig. 1 simultaneously into the film and the foam. The pattern shown in Fig. 1 had an average distance of about 0.25 inch between parallel fold lines in two sets which intersect each other at an angle of 90° and a distance of about 0.32 inch between parallel fold lines in two other sets intersecting each other at an angle of about 90° and intersecting each of the first two sets of parallel fold lines at angles of about 45°. The pattern had a maximum concave bend angle of about 7°. The resulting embossed laminate had a tough flexible top surface comprising the Tuftane® film strongly bonded to the foam material. The laminate was capable of being bent to a maximum concave arc of about 7° in an arc distance of about 0.3 inches with the deformations in the laminated surface being essentially limited to the pre-selected regular pattern of fold lines. The values of 7° and 0.3 inches correspond to the pre-selected arc on the roof of a motor vehicle to which the laminate will conform.

It is preferred to use the deformable sheet or the foam material as the adhesive for laminating by adhesively activating either the foam or the sheet at an elevated temperature to supply the bonding adhesive; however, many adhesives are suitable other than the foam or the sheet material such as animal glue, epoxy adhesives, gums or starch. Preferred adhesives are quick setting adhesives activated by heat.

Comparative Example

A laminate was produced from the same foam and film material employed in Example I and by using identical manufacturing procedures except that the embossing roll had a rosette pattern of approximately 25 protrusions per square inch with the protrusions having a depth of about 0.06 inches (hill to valley) and with the protrusions comprising approximately 5% of the surface area of the roll. This resulted in a laminate having an embossed surface with a rosette design and having a tough flexible top surface comprising the Tuftane® film strongly bonded to the foam material. When the laminate was bent into a concave arc comparable to the arc to which the product of Example I was bent, the laminated surface wrinkled and deformed in irregular patterns.

Generally, a method in accordance with the invention of manufacturing a laminate capable of conforming to a three-dimensional configuration having concave and convex characteristics by the laminate deforming according to a pre-selected regular pattern, can be described as comprising:

(a) contacting a thermo-deformable sheet with a top surface of a sheet of flexible, open-celled foam having a thickness of at least 1/8 inch.

(b) simultaneously embossing in the sheet and foamed a pre-selected pattern comprising land, valley and sidewall areas (such as by passing the foam and sheet through a pair of embossing rollers having the desired pre-selected pattern reproduced in relief upon one of said rollers),

(c) said regular pattern of land, valley and side-walls being defined by at least three intersecting sets of parallel fold lines, said fold lines resulting in spaced-apart raised land areas on either side of the fold line, which land areas contact upon concave bending of the laminated surface along the fold line.

The geometrical characteristics of the three dimensional configuration to which the laminate is desired to conform are used as a means for pre-selecting the minimum characteristics of the three intersecting sets of parallel fold lines, particularly with respect to the distance between adjacent parallel fold lines and the minimum concave angle that can be accommodated by the fold lines.

Both the degrees and direction of curvature of any concave curve in the three dimensional

configuration can be represented by a set of three concave curves each corresponding to the concave curvature that can be accommodated by each set of parallel fold lines. Theoretically, only two concave curves in the x and y direction are required to obtain equivalent degrees of curvature and curve direction. However, it has been discovered that at least three concave curves and preferably four concave curves corresponding to the curves that can be acommodated by each intersecting set of parallel fold lines will more readily accommodate the various configurations of a three dimensional regular or irregular surface. Accordingly, with the present method, a laminate can be designed that will contour to any desired three dimensional configuration with deformations in the laminate surface essentially occurring in the pre-selected regular pattern.

The fold lines depicted in the figures have a "V" shaped cross section, however, any shaped cross section can be employed for the fold lines, such as a channel. It is only necessary that the fold lines have sufficient depth and width to result in spaced-apart raised land areas on either side of the fold line.

Definitions

Flexible, open-cell foam sheet material as used herein refers to foam normally considered flexible by those skilled in the art and also includes semi-rigid foams provided the semi-rigid foam is sufficiently flexible to permit the changing of its surface area as evidenced by the surface remaining free of visible folds or wrinkles when the sheet is bent into a three dimensional configuration having concave curves with a degree of curvature comparable to an arc having an arc radius of about 3 inches.

By visible folds or wrinkles is meant folds or wrinkles readily apparent to the unaided eye which appear as abrupt changes in the curvature of the concave curved surface of the laminate.

The magnitude of the maximum concave bend angle, A, (shown in Figure 3) refers to an empirically determined value rather than the value determined by direct measurement. The angle would be measured directly by actually measuring the degrees of the angle shown in Figure 3. The angle is measured empirically by bending a piece of laminate in a direction perpendicular to a set of fold lines until the land areas touch (as shown in Figure 4) and dividing the degree of the bend by the number of fold lines accommodating the bend. It has been observed that the empirical method results in substantially lower determinations for the size of the angle which is probably due to internal stresses within the laminate during bending that causes some deformation. Empirical values of about 2° to about 60° corresponds to direct measurements of from about 20° to about 140°.

WHAT WE CLAIM IS:—

1. A laminate capable of conforming to a specific three-dimensional configuration having concave characteristics by the laminate deforming according to a pre-selected regular pattern, said laminate comprising:

(a) a flexible, open-cell foam having a thickness of at least 1/8 inch and a deformable sheet adhesively laminated to a surface of the open-cell foam, said sheet having sufficient thickness and a strength to result in the laminated surface being less flexible than an unlaminated surface of the foam;

(b) a pre-selected regular pattern comprising land, valley and sidewall areas defined by at least three intersecting sets of parallel fold lines impressed into the laminated surface;

(c) each fold line resulting in land areas being spaced apart on either side of the fold line, which land areas contact upon concave bending of the laminated surface along the fold lines;

(d) each fold line readily accommodating bending of the laminated surface by deforming up to a maximum concave bend angle, A, at which angle contact of adjacent land areas interferes with additional concave bending;

(e) an average distance between two parallel fold lines within a set, d, and the maximum concave bend angle, A, at which a land area touches an adjacent land area being defined by the formulas $A \gtrless 180\ 1/\pi r$ and $d \lesseqgtr r/2$ sine $1/2A$, wherein l and r are geometric characteristics of a pre-selected concave arc of the specific three-dimensional configuration to which the laminate will conform with the deformations essentially limited to the pre-selected pattern, said pre-selected arc having an arc length l, and an arc radius r;

(f) the minimum angle of intersection between any two sets of parallel fold lines being 25°;

(g) the sum of the angles of intersection between one set of parallel fold lines and each other set of parallel fold lines being at least 75°.

2. A laminate according to claim 1, said laminate comprising:

(a) a flexible, open-cell foam having a thickness of at least about 1/8 inch and a deformable sheet adhesively laminated to a surface of the open-cell foam;

(b) a pre-selected regular pattern comprising land, valley and sidewall areas defined by at least three intersecting sets of parallel fold lines impressed into the laminated surface;

(c) each fold line within each set having a depth of from 0.04 inches to 0.50 inches which results in spaced apart raised land areas on

either side of a fold line, which land areas contact upon concave bending of the laminated surface along the fold lines;

(d) each fold line and the spaced apart raised land areas on either side of the fold line defining a maximum concave bend angle, A, at which angle contact of adjacent land areas interferes with additional concave bending;

(e) the distance between parallel fold lines within each set being from 0.1 inch to 1.5 inches, the maximum concave bend angle being from 2° to 60°, and the thickness of the film being from 0.5 mils to 20 mils;

(f) the maximum concave bend angle, A, at which a land area touches an adjacent land area being at least equal in degrees to 180 $l/\pi r$ wherein l and r are geometric characteristics of a pre-selected concave arc of the three-dimensional configuration having an arc length l and an arc radius r;

(g) the distance between parallel fold lines being equal to or less than the value obtained from the formula $d=r/2$ sine $1/2A$;

(h) the minimum angle of intersection between any two sets of parallel fold lines being 25°;

i) the sum of the angles of intersection between one set of parallel fold lines and each other set of parallel fold lines being at least 75°.

3. A laminate according to claim 1 or 2, wherein the foam is polyurethane foam having a thicknesss of from 1/2 inch to 2 inches, and wherein the distance between parallel fold lines is from 1/8th inch to 1 inch, the maximum concave bend angle is from 2° to 15° and the thickness of the deformable sheet is from 1/5th mil to 10 mils.

4. A laminate according to any one of claims 1 to 3, adhesively attached to the inside surface of a motor vehicle passenger compartment roof.

5. A laminate according to any one of the preceding claims, wherein the three-dimensional configuration is an upper surface of a passenger compartment of a motor vehicle and the maximum desired concave arc of the three-dimensional configuration to which the laminate is desired to conform with deformations being limited essentially to the pre-selected regular pattern, is an arc corresponding to a concave arc forming a portion of the upper surface of the passanger compartment having an arc length, l, of from 1/8 inch to 5 inches and an arc radius, r, of from 1 inch to 10 inches.

6. A laminate substantially as hereinbefore described with reference to the accompanying drawing.

7. An improved passenger carrying vehicle including a laminate according to any one of the preceding claims, said vehicle being of the type comprising motive means and a passenger compartment having a cover with concave curves particularly in the areas where the cover joins with sidewalls of the passenger compartment, wherein the improvement comprises the inclusion of said laminate as a headliner for the passanger compartment attached to and conforming with the inside surface of the passenger compartment cover, with the unlaminated surface of the foam being attached to the passenger compartment cover and the laminated deformable sheet surface being the surface exposed to the inside area of the passenger compartment.

8. A method of manufacturing a laminate capable of conforming to a three-dimensional configuration having concave and convex characteristics by the laminate deforming according to a pre-selected regular pattern, said method comprising:

(a) adhesively laminating a deformable sheet to a sheet of flexible open-cell foam having a thickness of at least 1/8 inch;

(b) impressing into the laminated surface a pre-selected regular pattern comprising land, valley and sidewall areas defined by at least three intersecting sets of parallel fold lines;

(c) each fold line resulting in spaced-apart raised land areas on either side of the fold line which land areas contact upon concave bending of the laminated surface along the fold lines;

(d) each fold line readily accommodating bending of the laminated surface by deforming up to a maximum concave bend angle, at which angle contact of adjacent land areas interferes with additional concave bending;

(e) the average distance between two parallel fold lines within a set being equal to or less than the value obtained from the equation $d=r/2$ sine $1/2A°$ wherein A° is the degree of the maximum concave bend angle having a magnitude equal to or greater than 180 $l/\pi r$ in which l and r are geometric characteristics of a pre-selected concave arc of the three-dimensional configuration to which it is desired that the laminate conform with deformations essentially limited to the pre-selected regular pattern, with l representing the arc length, and r representing the arc radius;

(f) the minimum angle of intersection between any two sets of parallel fold lines being 25°;

(g) the sum of the angles of intersection between one set of parallel fold lines and each other set of parallel fold lines being at least 75°.

9. A method according to claim 8, wherein the foam is a polyurethane foam having a thickness of from 1/2 inch to 2 inches, and wherein the distance between parallel score lines is from 1/8th inch to 1 inch, the maximum concave bend angle is from 2° to 15° and the thickness of the deformable sheet is from 1/5th mil to 10 mils.

10. A method according to claim 8 of manufacturing a laminate, substantially as hereinbefore described.

11. A deformable laminate whenever produced according to the method of any one of claims 8 to 10.

LANGNER PARRY,
Chartered Patent Agents,
59—62, High Holborn,
London, WC1V 6EJ,
Agents for the Applicants.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1979
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

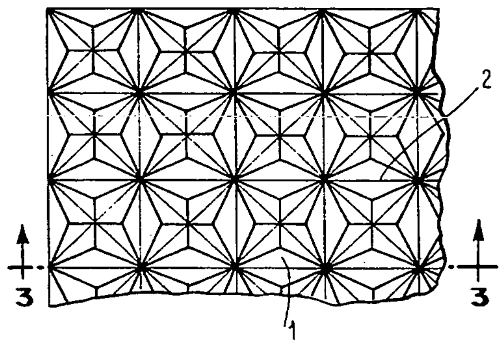

Fig. 1

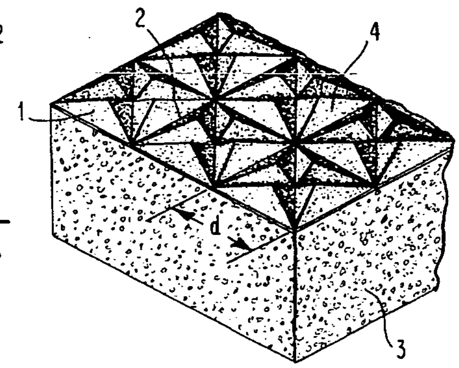

Fig. 2

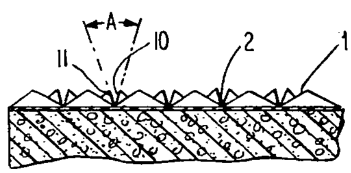

Fig. 3

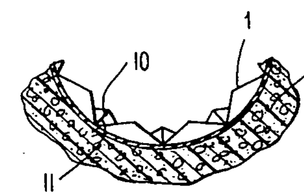

Fig. 4

Fig. 5